EECS C145B / BioE C165 Spring 2004: Practice Final

Question 1 (72)

Chose the correct answer for each question:

1. The purpose of the 180 degree pulse in the spin-warp sequence is to:

    - Decrease the time between the shutting-off of the gradient fields and the recorded FID.
    - Remove T_2^* decay.
    - Partially reverse T_2 decay.
    - Transfer magnetization components in the z (main field) direction to the x-y plane.
    - Double the signal-to-noise ratio.

2. Most of the received power in B-mode ultrasound imaging comes from:

    - Internal acoustic coupling within the transducer.
    - Reflection at boundaries between tissues that have different acoustic impedance.
    - Reflections from red blood cells.
    - Reflections from objects approximately a wavelength in diameter.
    - Acoustic signals due to the heart and arterial pulse that must be filtered out to get a stable image.

3. In whole-body 2D PET imaging, data from individual slices may be separated out because:

    - The layers of scintillator crystals are separated by aluminum sheets.
    - The photomultiplier tubes are able to resolve the energies of different photons as a function of slice position.
    - A gradient field in the z-direction stimulates nuclear decay only along a specific plane perpendicular to this axis.
    - Electronic collimation always tells us the exact chord along which the event took place.
    - Tungsten septa separate the crystal layers.

4. Below are the singular values of some matrices. Which has the best behaved inverse?

    - 10,10, 10^{-3}, 1

- 10^{-6}, 10^{-6}, 10^{-8}
- 100, 100, 100, 100, 100
- 10, 1, 0.1
- 1000 900 800

5. A 90 degree NMR pulse designed to excite a thick slice will look most like a:

   - Sinusoid with a decaying exponential envelope multiplied by a rect function
   - A sinc function multiplied by a rect function
   - A jinc function
   - A rect function
   - A linear frequency ramp

6. Beam steering and focusing in B-mode imaging is most effectively achieved by:

   - A mechanical arm that moves the transducer.
   - Providing a slightly different frequency to each crystal.
   - Delaying the application of a signal to different crystals.
   - Moving the crystals with a precision servo motor.
   - Using the delay in returned pulses to focus at a specific depth.
   - Options 2,3 and 5.
   - Options 3 and 5.

7. Strong oxidizing agents, such as those used to make explosives, usually have some free electrons to donate to chemical reactions. Explosives detectors at airports cannot detect these agents until they are mixed with some fuel. You might best be able to detect some of these chemicals mixed into bars of soap by:

   - Comparing the T_1 of the bar with a trusted bar.
   - Comparing the T_2 of the bar with a trusted bar.
   - Comparing the spin density of the bar with a trusted bar.
   - Using transmission ultrasound to find differences in the refractive indices of the bars.
   - Aiming a beam of positrons at the bar and counting the number of 511 keV gammas emitted using a gamma camera.

8. Identify the advantages of 3D PET relative to 2D multislice PET:

   - Facilitates dynamic studies.
   - Higher sensitivity.
   - Higher random coincidence rate.
   - Lower radial elongation resolution.

- Greater in-slice resolution.

9. Identify the properties of a Poisson process:

   - The waiting times are independent of the rate parameter.
   - The expected waiting time decreases exponentially the longer one waits.
   - The current waiting time is independent of past waiting times and the mean rate of events.
   - The current waiting time is independent of past waiting times.
   - The waiting times are exponentially distributed.
   - Options 2 and 4.
   - Options 1 and 4.

Question 2 (20)

You read the following in Diagnostic Imaging Online May 8, 2003:

Report from ARRS: PET proves its worth in the colon FDG-PET is a sensitive and accurate tool to detect colon carcinomas, according to a study presented Tuesday morning at the American Roentgen Ray Society annual meeting in San Diego.

Pennsylvania investigators compared whole-body F-18-FDG-PET with CT for initial staging, restaging, and recurrence of colon cancer. They found that PET was better than CT for disease detection in every major aspect of the study.

The researchers examined 35 patients with various stages of colon carcinoma who underwent 39 sets of PET and CT studies. They recorded a sensitivity, specificity, accuracy, positive predictive value, and negative predictive value of 89

The study's results validated findings presented last fall at the World Federation of Nuclear Medicine and Biology in Santiago, Chile.

Patients underwent whole-body PET scanning 45 minutes to an hour after a 5.6-mCi intravenous injection of F-18-FDG. They underwent contrast-enhanced CT imaging within a few weeks. All clinical, radiographic, and pathological results were correlated.

F-18-FDG-PET studies are sensitive and accurate for detection of colon carcinoma at various stages, said principal investigator Dr. Imtiaz Ahmed from the Mercy Catholic Medical Center in Darby, PA.

"We recommend F-18-FDG-PET studies for staging, restaging, and evaluation of recurrent colon carcinoma," Ahmed said.

For more from the archives of Diagnostic Imaging:

F-18-FDG-PET sheds light on managing colon carcinomas

– By Harold Abella

Why might you have anticipated that PET would be better than CT for colon tumor detection?

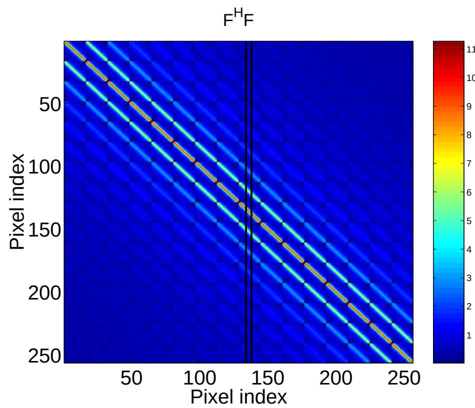
Question 3 $(20 + 5 + 10 + 10 + 10 = 55)$

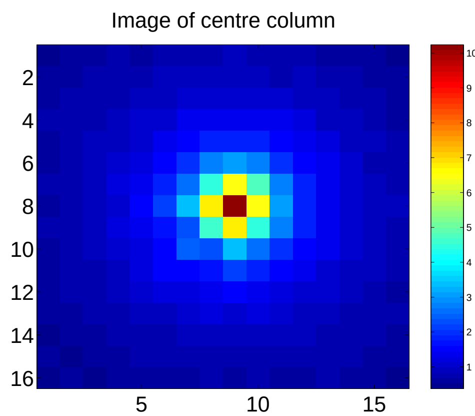
Draw and label a PMT and explain in detail:

1. What a PMT detects.
2. How detection is accomplished.
3. How amplification is accomplished.
4. How energy resolution is accomplished.

Question 4 (20+20**b**+10**b**)

You are analyzing the performance of a proposed PET system design. You have calculated the projection matrix $\mathbf{F}$ based on simulated photon data. You form and plot an image of $\mathbf{F}^T\mathbf{F}$. You take its central column and reverse column stack it to form an image.





1. What does the image in the right figure represent?
2. To check whether the system suffers from severe radial elongation effects, which columns of $\mathbf{F}^T\mathbf{F}$ would you unstack to view this effect? Explain.
3. How could you try to compensate for radial elongation using this information?

Question 5 $((10 + 10 + 10 + 10 + 10))$

Explain whether LSO is superior to BGO in terms of the following physical parameters and discuss the impact on scanner design and performance:

1. LSO attenuation length = 1.2 cm, BGO attenuation length = 1.1 cm.
2. LSO photons/MeV $= 25,000$, BGO photons/MeV $= 8,200$.
3. LSO decay time = 40ns, BGO decay time = 300ns.
4. LSO emission wavelength = 415nm, BGO emission wavelength = 480nm.
5. LSO intrinsic decays per second = 300, BGO intrinsic decays per second = 0.

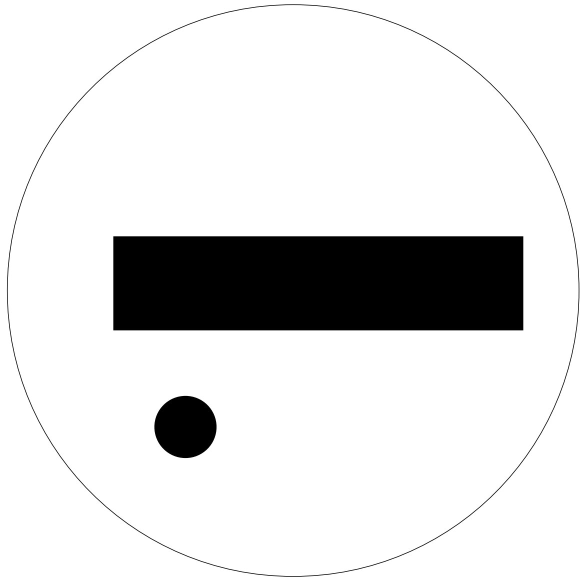
Question 6 (60)

Fill in the following table:

	Type of signal	Property(ies) which modifies(y) signal
Chest x-ray or mammography		
X-ray CT		
PET or SPECT		
MRI		
Ultrasound		
Optical imaging		

Question 7 ((15 + 15))

Projection MRI imaging is to be performed on the object below. Angles are measured anticlockwise from the horizontal.



Show the projection obtained when a gradient field is applied at 135 degrees.

Show the projection obtained when a gradient field is applied at 90 degrees.

Question 8 ((60))

With the assistance of diagrams, explain how you would perform 2D Fourier transform MRI of an image of $M \times M$ pixels is required. You explanation should include both data acquisition and reconstruction methods. Assume that a simple spin-warp sequence is used to obtain the acquired signal.

Question 9 ((10 + 10 + 10))

An image is acquired using a spin-warp imaging sequence, but the values of TR and TE used have been forgotten. Given the information in figure 1, determine whether TR and TE were long or short, relative to T1 and T2, respectively, when the image in figure 2 was acquired.

Check one box:

		Answer
TR short	TE long	
TR long	TE short	
TR long	TE long	
TR short	TE short	

Suppose the fourth blob was the brightest blob. What would you say about TR and TE?

		Answer
TR short	TE long	
TR long	TE short	
TR long	TE long	
TR short	TE short	

Check one box:

Suppose the first and second blobs were bright and the third and fourth dark. What would you say about TR and TE?

Check one box:

		Answer
TR short	TE long	
TR long	TE short	
TR long	TE long	
TR short	TE short	

Question 10 ($20 + 20$)

In a B-mode image acquired using a linear array with 256 crystals, you spot the brachial artery and position the PW range gate window at the artery center. You measure a depth of 15 mm. The artery is oriented at approximately 45 degrees with respect to the incident ultrasound wavefront. The ultrasound machine is calibrated to $c = 1500$ m/s.

1. The imager sends a pulse of 0.01 ms duration at a carrier frequency of 10 MHz into the tissue. Draw, scale the indepedent variable axis and label the graph of the gain of the receiver as a function of time to maximize the component of the received signal that comes from the artery center.

2. A timer inside the imager starts timing immediately after the imager is switched into receive mode after the pulse is applied. The pulse returns in 31 μs. What is the speed of the blood in the artery, and is it flowing toward or away from the transducer? You can leave you answer in fractional form.

Question 11 (20)

Derive a formula that gives the minimum number of angular projections needed in SPECT for a circular object n cm in diameter when the resolution is ϵ mm and the detector is $5n$ from the center of rotation.

Draw a diagram to illustrate your proof.

Question 12 (30)

Show how you would find a solution to the inverse problem below (This entails finding the values for the pixels of the image a_i, given the projections p_k). Use the algebraic reconstruction technique (ART).

$$\mathbf{p} = \mathbf{F}\,\mathbf{a}$$

a_1	a_2	$p_1 = 4$
a_3		$p_2 = 7$
a_4		$p_3 = 2$
	a_5	$p_4 = 2$
$p_5 = 10$	$p_6 = 5$	

Question 13 $(10 + 20 + 10)$

Values of T1 and T2 for brain are:

	T1 (ms)	T2 (ms)
CSF	3000	40
gray	1100	30
white	800	35
tumour	1200	80

You are able to vary TR and TE, such that any combination of the following is allowed:

TR	3000, 500 ms
TE	30, 80 ms

1. What is the optimal combination for imaging gray matter-white matter contrast?
2. What is the optimal combination for delineation of the CSF space?
3. Show a practical full pulse sequence for tumor detection.

Question 14 $(15 + 10 + 15\mathbf{b})$

You are designing a B-mode ultrasound system for imaging the prostate gland.

1. The preliminary images from the instrument are disappointing because only some of the walls of the gland are visible. You would not be able to identify all types of tumor from these images. What is going wrong, and how could you modify the electronics and/or software to improve the images?

2. A former employee designed a linear probe for the system. Should you propose a design change? Why?

3. The system is intended to be used to locate the prostate so that simultaneous PET imaging can be performed. A consultant to your company is worried that the transrectal probe will produce severe PET image artifacts. Is this a problem? Explain.

Question 15 $((30 + 20))$

1. During systole, an artificial heart pumps blood from rest at an acceleration that decreases linearly from 2 m/s^2 at $t = 0$ to 0 m/s^2 at $t = 0.5$ seconds. Draw the CW ultrasound signal of the resulting flow and the sonogram of this waveform. Assume an insonation frequency of 1.5 MHz and an angle of 60 degrees between the incident radiation and the oncoming flow. Scale and label all axes.

2. Above we assumed all the blood travels at the maximum velocity. Qualitatively draw the sonogram for part one in which the blood flow is more laminar.

Question 16 $(30 + 20\mathbf{b})$

You are seeking venture capital funding for a new private hospital that will provide comprehensive health services and house part of the research division of a pharmaceutical company. This company will need to test new drugs on small animals and non-human primates before these can be tested in humans. Make a wishlist for imaging instruments and associated support equipment and justify the need for each.

Question 17 (30)

Explain why PET resolution will never be better than approximately 1mm. Why is this theoretically not the case with SPECT?

Question 18 $(15 + 15)$

In performing steepest descent optimization on the function:

$$f(x, y) = 5x^8 - \sin(\theta)$$

we find ourselves at the point $(x, \theta) = (1, \pi)$.

1. In what direction do we take our next step? (do not normalize to a unit vector)
2. Will a step size of 10^{-10} be acceptable? Explain.

Question 19 (20)

Explain in detail how natural paramagnetism and paramagnetic tracers may be employed in MRI to provide functional contrast.

Question 20 $(15 + 30\mathbf{b})$

The book "MRI basics" uses diagrams such as the one below to explain contrast in spin-echo images:

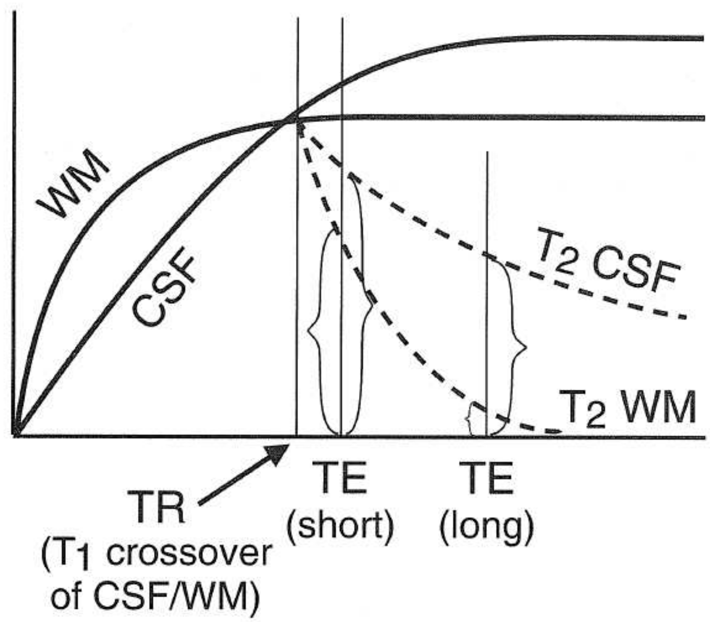


Figure 6-11. Recovery and decay curves of WM and CSF for a TR corresponding to the crossover point of CSF and WM.

Source: Hashemi p. 65

1. Why do you think the authors do not label the y-axis of the graph?
2. Explain the true physical reality with reference to the behavior of the field components M_{xy} and M_z, T_E and T_R, and contrast selection (Hint: Drawing two separate graphs might help resolve the issue in part 1 of this question).

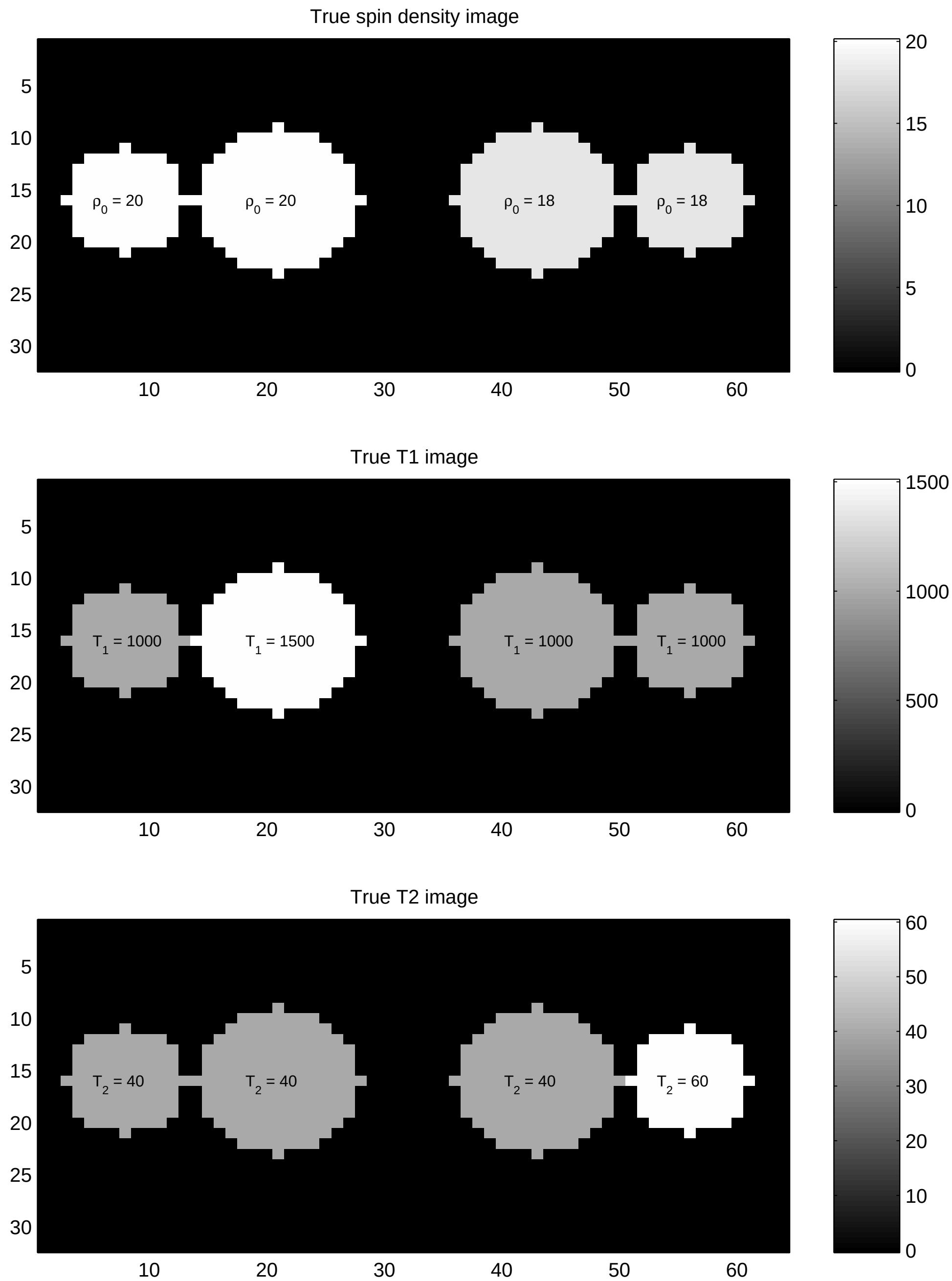


Figure 1: True T1, T2 and spin-density (ρ_0) distributions

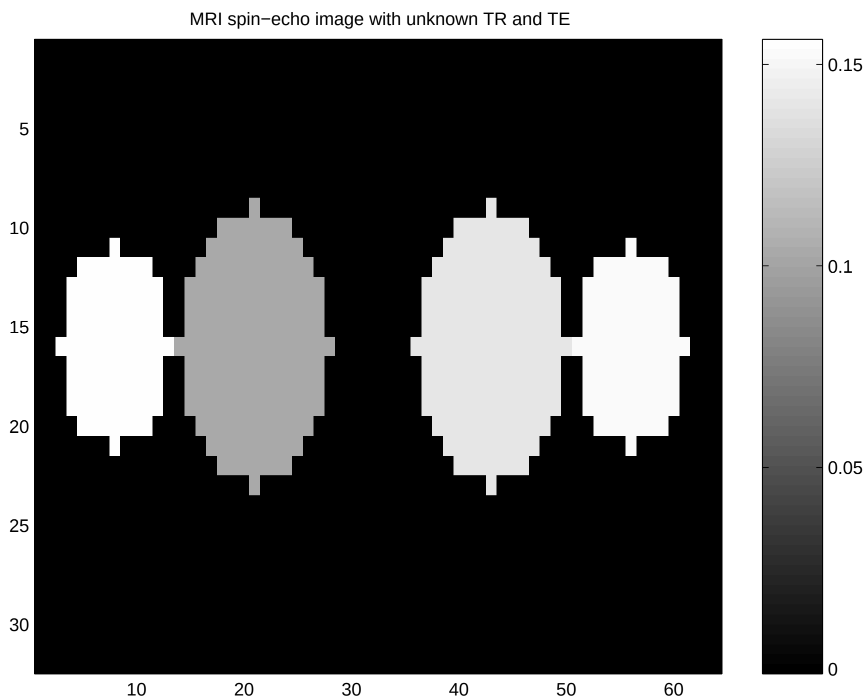


Figure 2: Image obtained with TE and TR unknown